MANUAL OF METHODS IN FISHERIES BIOLOGY

compiled by

T. LAEVASTU

Fascicule 5

Section 2. Observations on the physical and chemical environment

2.3 Oceanographic and limnological observations and analyses

2.3.1 Physical measurements

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2.3 OCEANOGRAPHIC AND LIMNOLOGICAL OBSERVATIONS AND ANALYSES

2.3.1 Physical measurements

Hydrographical observations are made and samples are taken at stations whose position is usually planned beforehand (see Section 1).

It is of the utmost importance that everything should be in readiness for the work of a station; all clearing up after each station should be done without delay, and log sheets should be prepared, instruments checked and cleared, and sampling bottles got ready, while the ship is underway from one station to another.

2.3.1.1 Hydrographic equipment

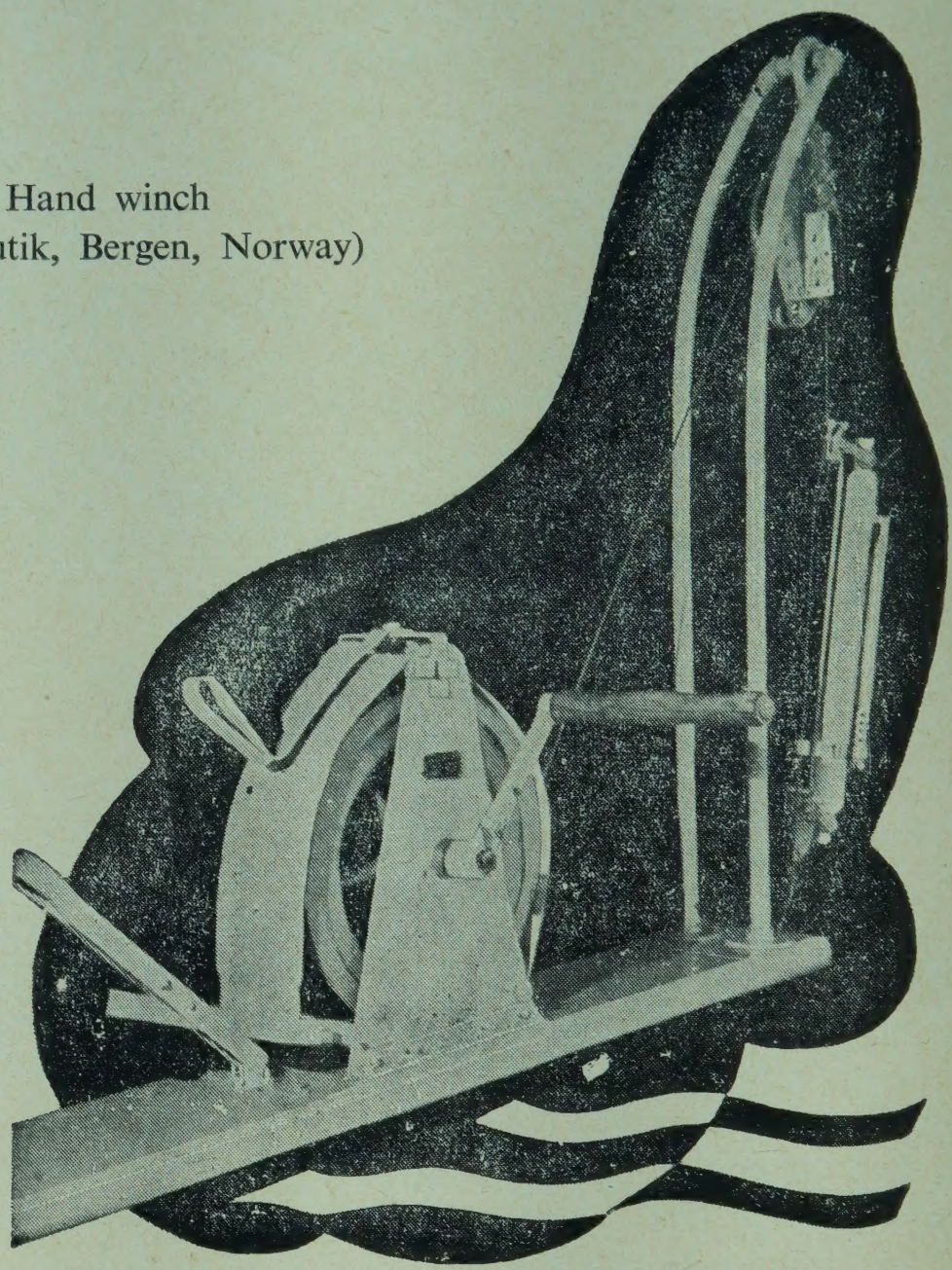
Practice is necessary for the proper handling and care of all instruments. It should always be borne in mind that since it is extremely difficult and often impossible to repair broken instruments on small vessels, the failure of an instrument may mean the failure of the entire program of work and a voyage may have been made in vain. Therefore, in addition to skill and care in handling, the instruments must be properly secured to the ship even during calm weather. An unexpected wave, when the sea is smooth, such as that generated by a passing ship, has often caused great damage in a ship's laboratory where no precautions had been taken. If possible, spare instruments should be carried.

Instruments should always be properly dried and cleaned immediately after use. Metal instruments should be rinsed with fresh water if possible. Greasing and degreasing is a regular job on certain types of oceanographical equipment. Silicon grease should be given preference.

Mounted hydrographic winches of different types are part of the ship's equipment and are not discussed here. Portable hand winches, used on small boats (Figure 1) must be securely fixed. These winches must have two brakes: one to regulate the lowering speed and a second to arrest the cable effectively. Cables, of which the best kinds are rustless, are strong and flexible; but nevertheless they must be handled carefully to avoid twisting, and should be checked often at wearing and weak spots. The weight at the end of the cable should be sufficient to allow different lowering speeds and to prevent sliding on the meter wheel. The meter wheel should be easily readable both by the winch and instrument operators (Figure 2).

Many different types of water samplers (bottles) are in use (Figures 3 to 5). These can be classified as single and series samplers. The most common single type is the Pettersson-Nansen bottle (Figure 3), which should not be used at greater depths than 200 meters. Series samplers either reverse themselves when closed by a "messenger," or are equipped with a reversible thermometer frame. A messenger is hung below each bottle. Reversing of the

FIGURE 1. - Hand winch
(Courtesy Bergen Nautik, Bergen, Norway)



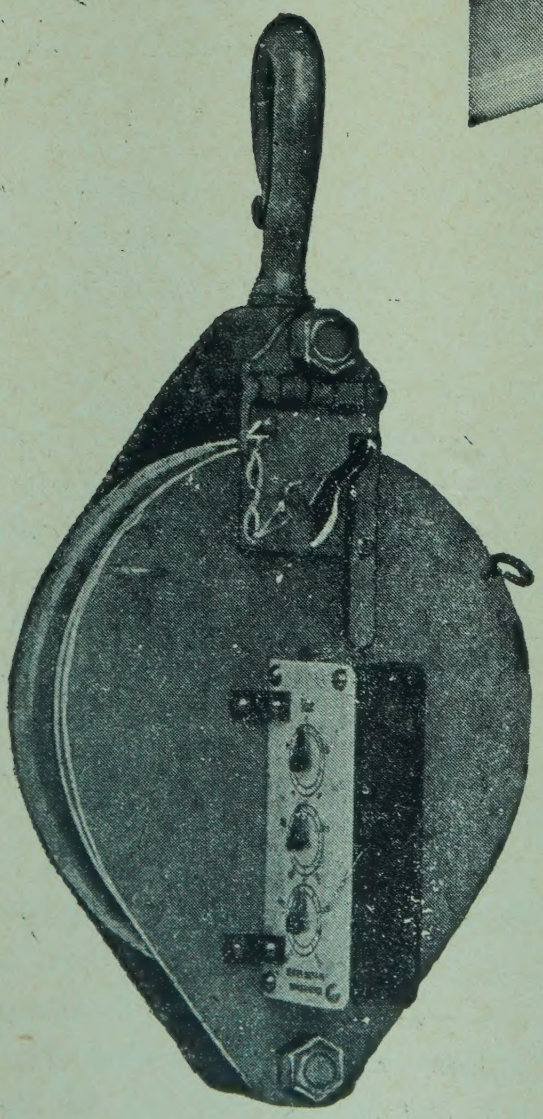


FIGURE 2. - Meter wheel
(Courtesy Bergen Nautik, Bergen, Norway)

bottles is initiated by sending down a messenger from the ship; this reverses the first bottle and releases its messenger which causes the second bottle to reverse, and so on. This chain reaction can be detected through the line so that if a bottle should not reverse and will not release its messenger, the observer will know that the action is incomplete. Bottles sometimes reverse and close prematurely (*a*) if the end weight is too light, (*b*) if the cast is lowered too rapidly and (*c*) in heavy seas. Care should be taken that the bottles are fastened to the wire, so that no sliding occurs and that they remain open until the messenger strikes them.

2.3.1.2 Current measurements

Whenever possible, surface currents should be observed and recorded in the scientific logs. Allowances must be made in coastal waters for tidal currents which are superimposed on permanent or temporary currents caused by other phenomena such as wind. There are several methods, direct and indirect, for measuring and estimating currents.

2.3.1.2.1 *Direct measurements*

The direction and relative velocity of currents can be determined visually by observing the sea surface around anchored buoys, single small rocks, or similar objects. The accumulation of floating detritus on the surface sometimes gives an indication of the convergence lines of currents. The cheapest and simplest equipment for surface current observation from anchored vessels is a current cross (Figure 6). The line to which a cross is attached must be light in weight and marked in meters or fathoms. The length of line pulled out by the current cross per unit of time gives the speed: direction is estimated from the direction of the line. When measuring subsurface currents with current crosses the area of the cross must be much larger than the surface of the buoy from which the cross is suspended. At night the buoy can be equipped with light. If the vessel is equipped with radar, a radar reflector on the buoy will facilitate the operation. There are several types of direct-reading current meters for use on anchored ships. If only one anchor is being used, the swinging of the ship around the anchor must be taken into account and the measurements taken several times. In areas with tidal currents the measurements should be made at intervals during at least two tidal periods.

The Carruthers simple current meter uses a bottle, half filled with jelly and a compass floating in it. This meter is especially useful for measuring bottom currents. The bottles are sent down fixed to a weight or to a special neutrally buoyant holder in the desired depth by means of anchored buoys. The jelly bottle is tilted by the current, the cold water solidifies the jelly and the amount

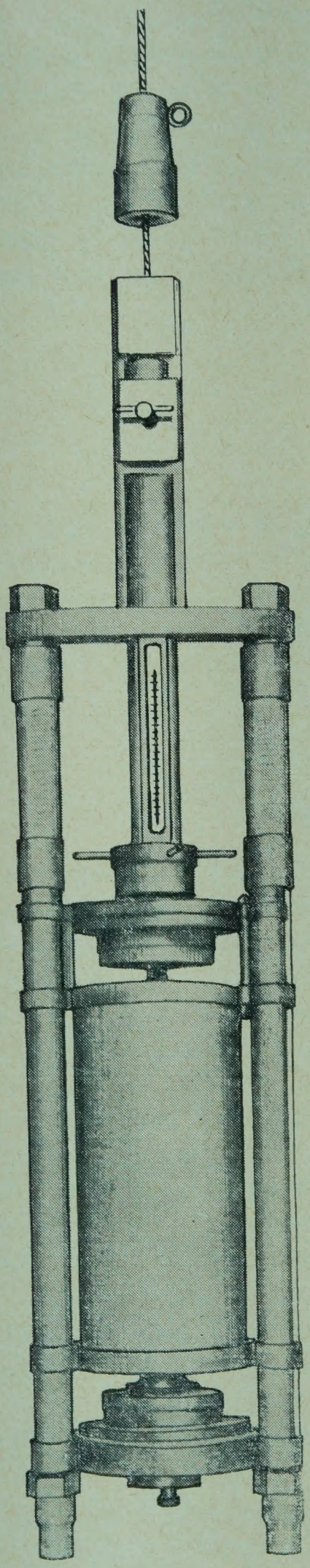


FIGURE 3. - Pettersson-Nansen bottle

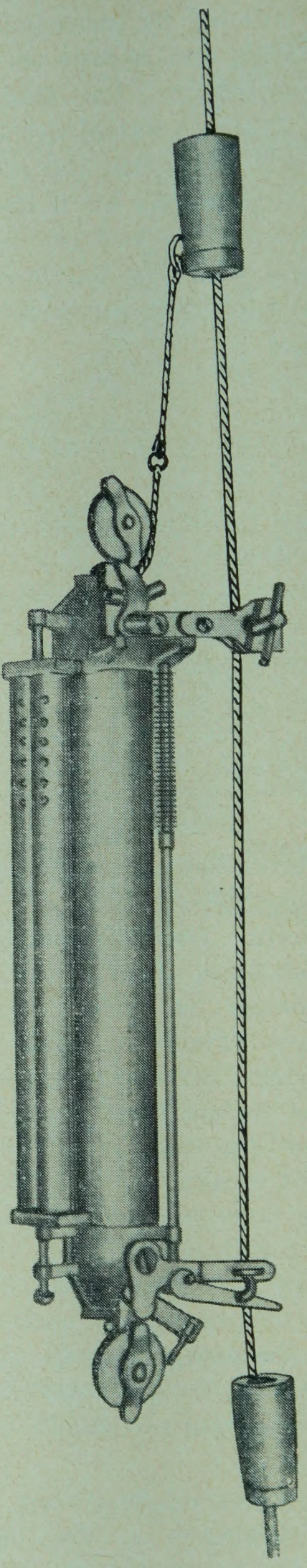


FIGURE 4. - Nansen reversing water bottle

of tilt gives, from calibration tables, the current speed. The compass gives the direction of tilt, hence the direction of current (Figure 7).

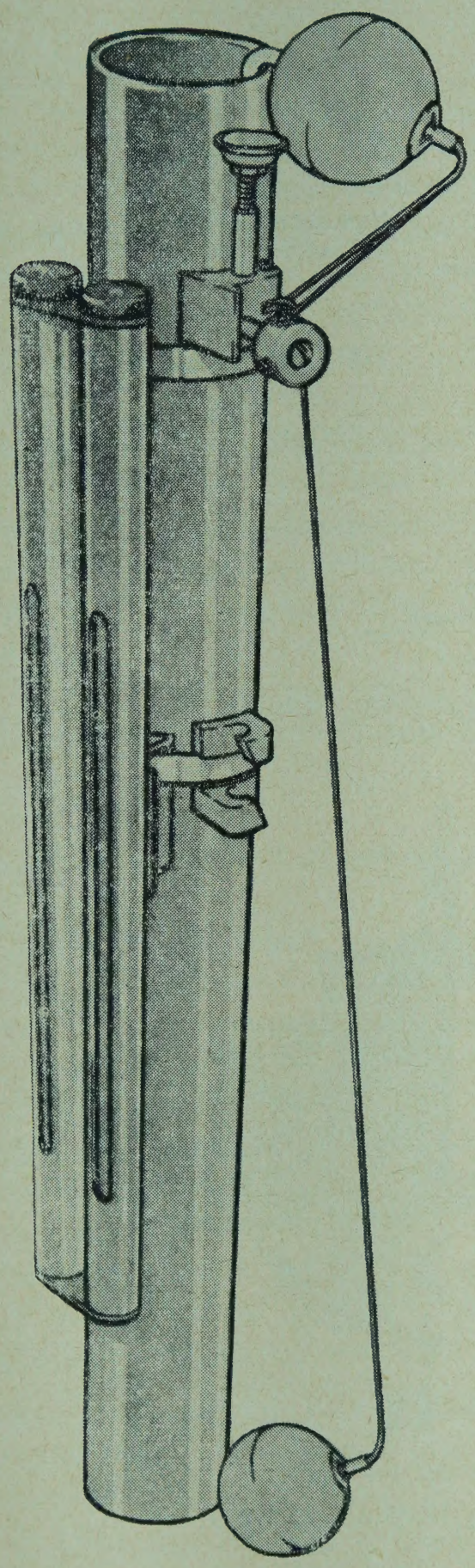


FIGURE 5. - Frautschy bottle
(Courtesy Hytech Corp., Inglewood, Calif., U.S.A.)

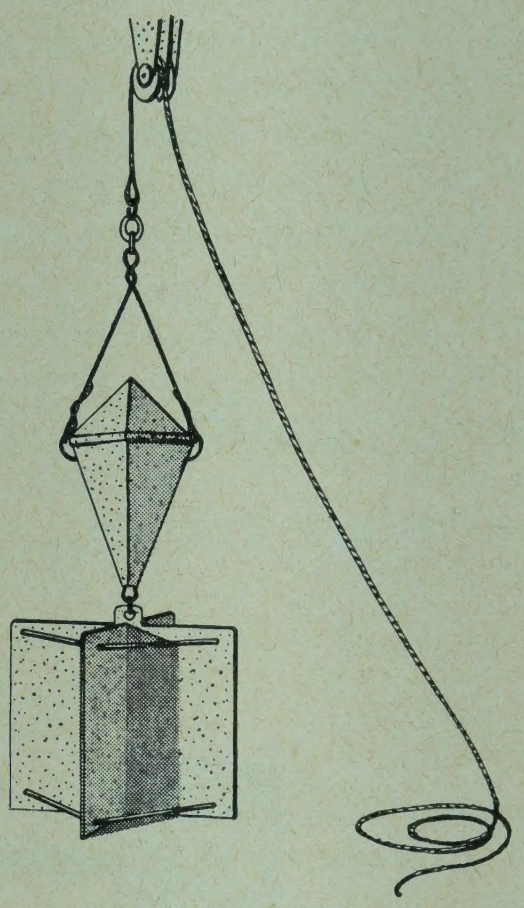


FIGURE 6. - Current cross

The Ekman current meter (Figure 8), the most common in use in the past, needs careful handling. The operator must check that the propeller turns in friction-free manner and that the release and closing mechanisms work properly. Sufficient weight below the meter should be used to keep the meter horizontal

in the water, otherwise the special compass in the meter will not function properly. Movement of the ship in waves causes considerable errors in the Ekman and other propeller-type current meters suspended from the ship.

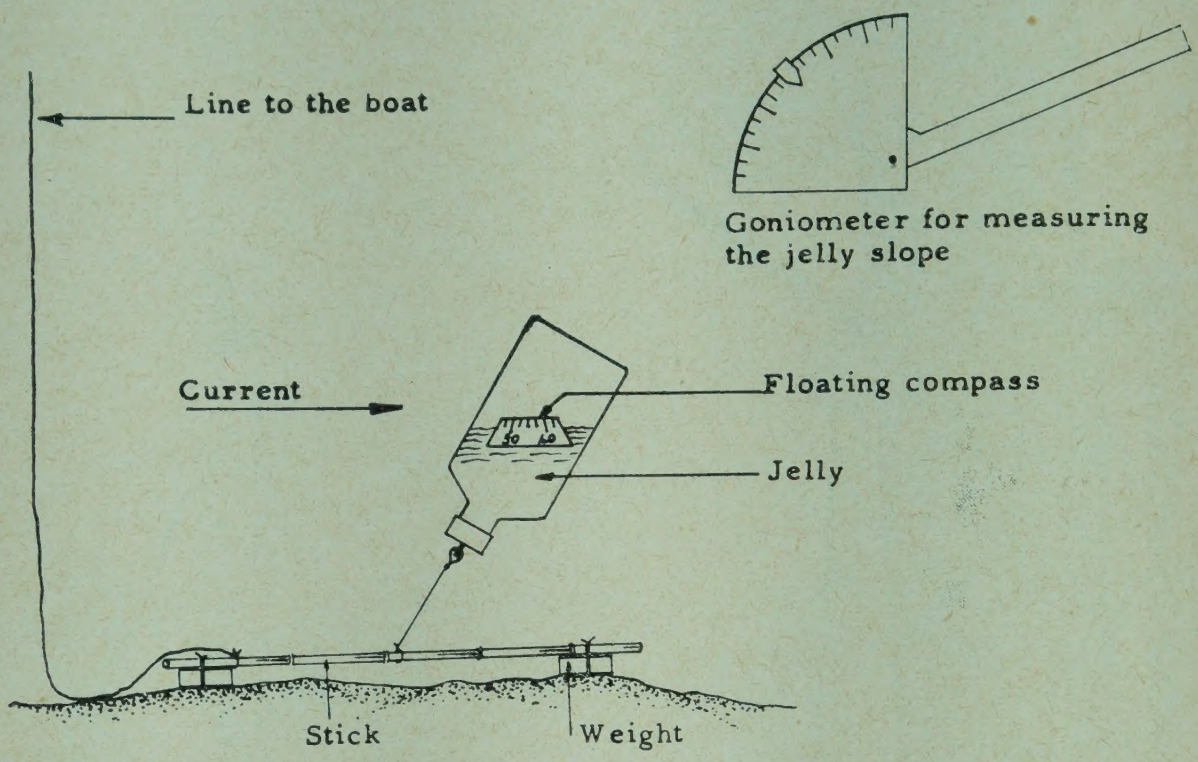


FIGURE 7. - Carruther's jelly bottle

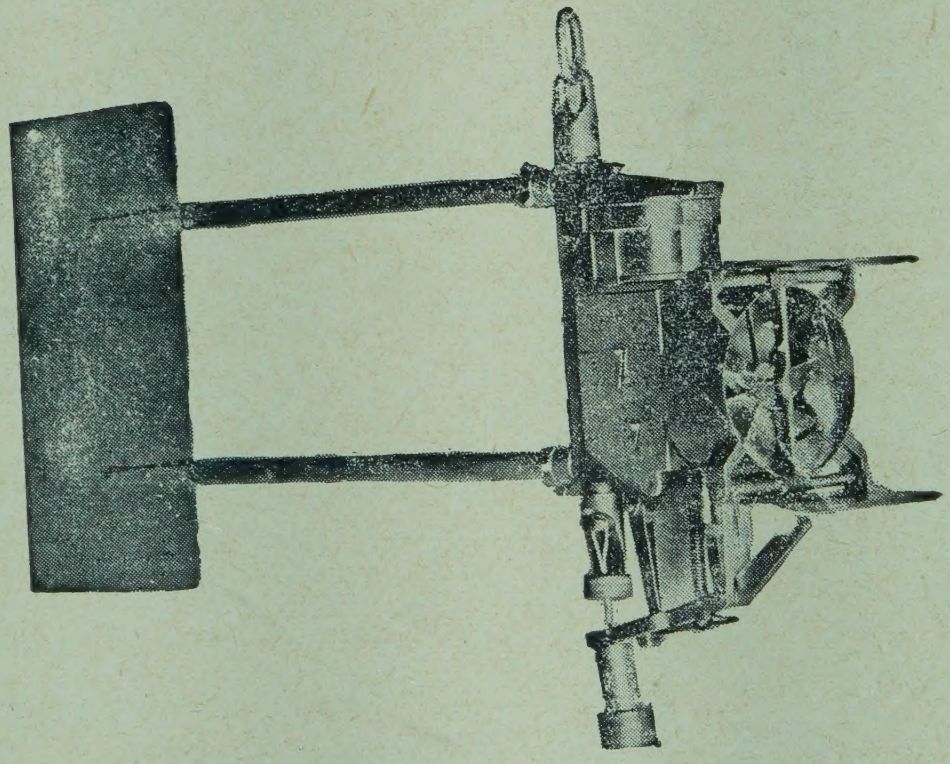


FIGURE 8. - Ekman current meter
(Courtesy Bergen Nautic, Bergen, Norway)

Continuous current meters are available, which record currents and their direction for two weeks. These are suspended in the water by buoys and anchors. There are also several other types of simple current meters, such as Carruthers current cones, etc. A more expensive and complicated instrument for measuring surface currents is the Geomagnetic Electro Kinematograph

(G.E.K.). This works on the principle that an electric current is induced when a body of water moves in the earth's magnetic field. Special skill is needed for handling this instrument.

2.3.1.2.2 *Indirect methods*

In offshore waters currents may be computed from the drift of the ship. This drift is determined by the difference in unit time of the fix of the ship estimated from its course and speed and the astronomical fix. Drift cards and drift bottles are often used. The bottles are filled with sand so that when floating only a small part of the neck projects through the surface. A card is enclosed in the bottle with a number and the address to which the finder should send the card, and a request to the finder to record the date and location of discovery of the bottle. The place and date of release and number are recorded and compared with place and date of recovery. Drift bottles are generally used in semiclosed basins to investigate special features of the surface currents. They give only a rough picture of current paths. The bottles are influenced by winds and waves, and these and other factors must be considered when evaluating the results.

Conclusions about the current patterns can also be drawn from ecological indicators (mainly plankton and suspended matter).

2.3.1.2.3 *Determination of stream flow*

Average width and depth. A series of measurements is made of the stream station. At least five measurements should be taken of the width of each station; each end, middle, and midway between these are usually taken. More measurements should be made if the stream is particularly uneven. The average is then obtained.

Depth is measured at points of width measurement. Depth is taken in the middle of the stream, and at a point halfway between the middle and each shore. If the stream is wide or the bottom uneven, more than the three soundings should be taken. The average depth is determined by adding the readings and dividing by one more than the number of soundings taken. This allows for the zero readings at the shore.

Volume. Volume will be recorded in cubic meters per second where the flow is greater than 1 m^3. Flows less than 1 m^3 should be given in liters per minute (1 min^{-1}).

The following formula is used to determine the volume flow:

$$R = \frac{W\ Da\ L}{T}$$

Where R is rate of flow

W is average width of section

D is average depth of section

T is average time in seconds required for a float to traverse the distance L

L is the length of the stream section

a is a constant for correction of stream velocity. If the bottom is rough and strewn with rocks and coarse gravel, a is taken as 0.8; if the bottom is smooth a is taken as 0.9.

As straight a section of stream as possible is selected for this test. Measure the length, width and average depth of this section. Then ascertain the length of time it takes for a small float (about the diameter of a lead pencil and 75 mm long) to traverse the distance. Three trials should be run with the float, and the average time recorded.

Substitute the proper figures in the formula and determine the volume flow.

Velocity. Velocity may be described in terms of centimeters per second flow according to the following table:

Very slow	0-10	cm	per	second
Slow	11-25	"	"	"
Moderate	26-50	"	"	"
Moderately rapid	51-75	"	"	"
Rapid	76-100	"	"	"
Very rapid	101-200	"	"	"
Torrential	201 and above			

2.3.1.3 Temperature measurements and corrections applied

2.3.1.3.1 *Surface temperature*

It is advisable to record sea surface temperature at frequent intervals when the ship is underway because rapid changes in temperature with distance are generally indicative of current divergences and convergences whose presence is always of considerable significance. The temperature of surface seawater (the upper 50 cm) can easily be measured by the " bucket " method while underway. In large ships the temperature of condenser intake water is recorded continuously.

For temperature determination the sample of water should be taken with a special bucket on the leeward side far from all outlets. The bucket should not have been in direct sunshine prior to use. It should be towed astern for at least three minutes. If the bucket is equipped with a special fixed thermometer, this should be read immediately the sample arrives on board. When a loose thermometer is used, it is held by the upper end and moved around in the water for a minute or two. The thermometer should have a small heat

Form 1. - Stream survey

Name of stream ..... Main drainage .....

Stream section .....

Watershed: Cultivated or not, wooded, open swampy, flat, rolling, hilly, mountainous .....

Bank vegetation: .....

Aquatic vegetation - Algae: Abundant ..... Common ..... Rare .....

Higher plants: Abundant ..... Common ..... Rare .....

Irrigation pumps, diversions, barriers, dams .....

Pollution .....

Water supply: Present level ..... High-water level .....

Gradient: Slight ..... Moderate ..... Steep .....

Pools: Size ..... Type ..... Frequency .....

Spawning areas: None ..... Few ..... Common ..... Abundant .....

Stream bed: % Bedrock ..... % Rubble ..... % Gravel ..... % Sand .....

% Mud ..... % Silt ..... % Boulders .....

Fish present .....

Average width ..... Average depth .....

Volume flow ..... Velocity .....

Color ..... Turbidity ..... Water temp. ..... Air temp. .....

pH ..... O_2 ..... CO_2 ..... MO Alkalinity ..... ph-th .....

Investigator .....

capacity and it should not be lifted out of the water for reading. The reading should be made with an accuracy of + 0.2°F or + 0.1°C. A surface bucket is illustrated in Figure 9.

2.3.1.3.2 *Temperature in the depths*

Water samplers are usually fitted with frames to hold two reversible thermometers (Figure 10). One thermometer is protected against pressure and the other is unprotected. The unprotected thermometer serves for checking and/or recording the depth to which the sampler has been lowered. Simpler and cheaper samplers, which are often suitable for fisheries work (e.g. the Frautschy bottle), have usually one reversible thermometer (pressure protected).

The cast is made from a work platform or from the weather side of the ship, and the depth of the water must be checked from the bridge before the cast. If possible, samples should be taken at standard depths of observation: 0, 10, 20, 30, 50, 75, 100, 150, 200, (250), 300, 400, 500, 600, (700), 800, 1,000, 1,200, 1,500, 2,000, 3,000, 4,000 meters. At least five minutes should pass after a cast has been lowered into position before the messenger is sent to close the bottles, to allow each thermometer to register the temperature of the water layer in which it lies. Before the messenger is dropped the angle of the wire with the sea surface is measured, so that the actual depth of the samples can be calculated. In rough weather when hauling in, care must be taken that the bottles do not hit against the ship. When the samplers are hauled aboard and loosened from the wire, care must be taken not to turn them on their sides but place them vertically into the rack as they come from the water.

The thermometers should be read with a thermometer reader, the main one to an accuracy of ± 0.01°C and the auxiliary to ± 0.1°C. The auxiliary thermometer shows the temperature of the thermometer at the time of reading and serves for correction of the actual temperature.

Bathythermographs (Figure 11) are used for continuous recording of temperature and depth in upper water layers. The BT can be lowered either at the station or underway. The record is made by the instrument on smoked slides, one of which is used for each lowering. In operation the BT is lowered into the surface water and held there for about 30 seconds to allow the thermometer to adjust to the temperature of the sea surface.

After that more wire is paid out. The length of wire run out during underway measurements depends on the ship's speed and the condition of the control gear. Several trial runs should be made to determine the length of wire necessary to reach the depths sought. The surface temperature should always be taken with the bucket thermometer when the BT is lowered and recorded in the BT log. The BT should never be kept in temperatures exceeding 105°F (40°C).

The slides are numbered and kept in special boxes. A special magnifying glass with graded scales for depth and temperature is used to read these slides.

Exact instructions for the use of the BT are given in Section 2.3.1.3.4.

FIGURE 9. - Surface bucket with thermometer

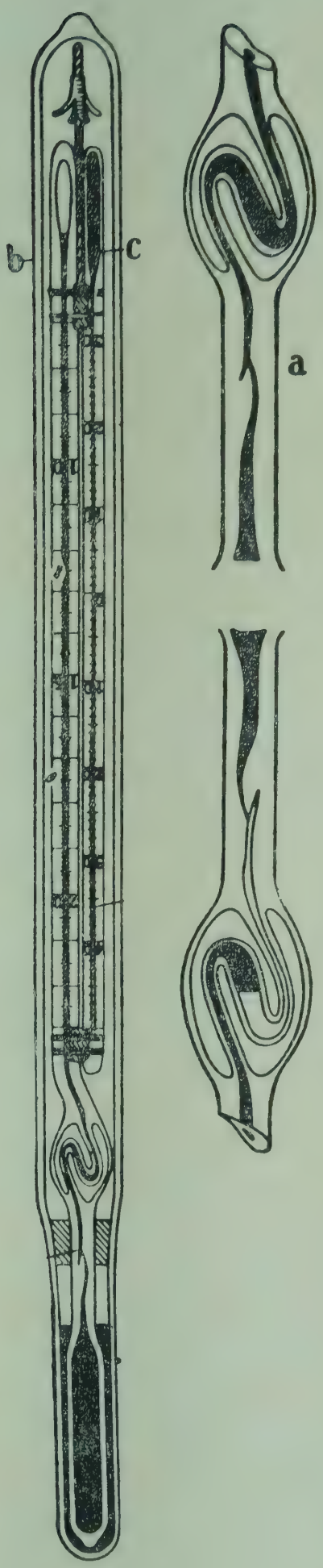


FIGURE 10. - Reversing thermometer (pressure protected)

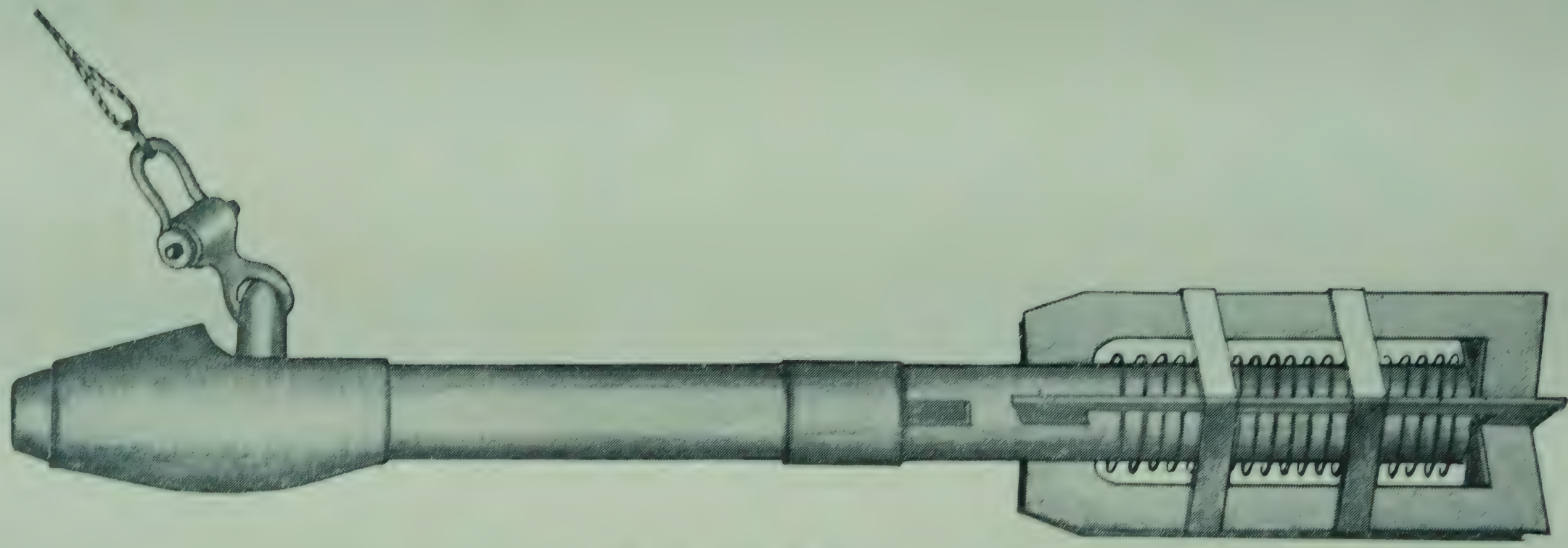
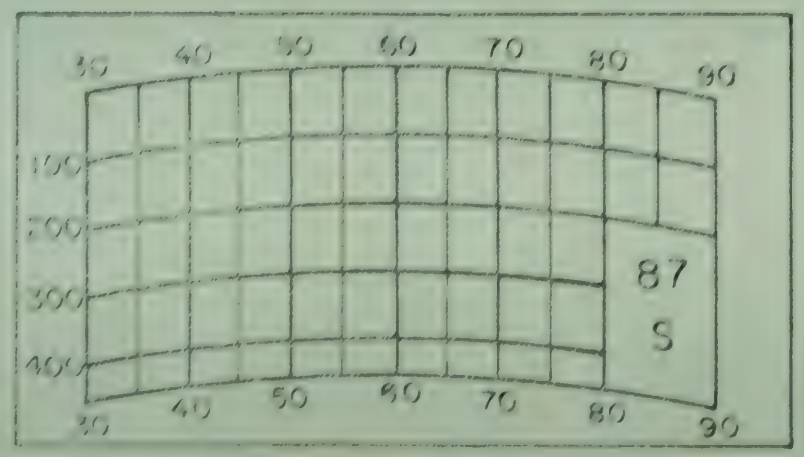
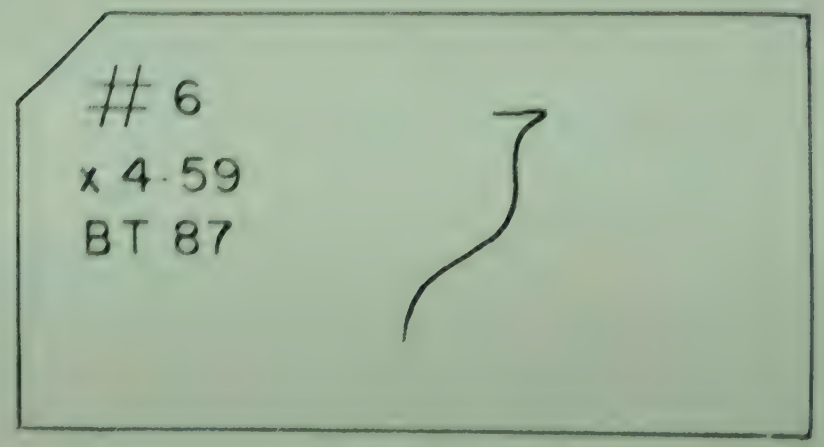


FIGURE 11. - Bathythermograph



Grid for reading recording



Typical recording

BTs provided with water samplers are also available (so called "sea samplers"). Those samplers take samples automatically at selected depths during the lowering of the BT. However at present none of the sea samplers available are entirely satisfactory: all the water bottles tend to leak, and the samples are relatively small and permit only determination of salinity.

2.3.1.3.3 *Reading, correction and care of reversing thermometers*

(The following is an extract from an undated mimeographed paper *Measurement of sea temperature and corrections applied*, by T.G. Thompson, R.J. Robinson and C.A. Barnes. Seattle, University of Washington.)

Each reversing thermometer consists of two thermometers, the reversing thermometer proper and the auxiliary thermometer. These are sealed in a heavy glass tube in order to prevent the pressures at the greater depths from having an effect upon the mercury bulbs proper. The larger bulb of the reversing thermometer is immersed in a mercury jacket contained in the heavy glass tube. This arrangement permits rapid conduction. The capillary tube of this thermometer is contracted just above the large bulb so that when the instrument is inverted the column of mercury breaks at the contraction. Part of the mercury falls into the small bulb and overflows, filling part of the graduated stem. The actual volume of mercury flowing into the small bulb is dependent upon the temperature of the mercury at the time of reversal of the instrument.

The scale on the thermometer has the lowest values at the small bulb, but the stem is graduated with respect to the mercury contained originally in the large bulb. A correct reading of the thermometer is possible only when it is read at exactly the same temperature as that at the time of reversal and when the graduations are exact. If the temperature at the time of reading is greater than at the time of reversal, the mercury in the small bulb will have expanded. To obtain the actual temperature, a correction for this must be made and the purpose of the auxiliary thermometer is to give a means for making this correction. A change in the volume of the mercury corresponds to a change in temperature as recorded on the scale of this thermometer, while in the reversing thermometer a change affects only that portion of the mercury contained in the smaller bulb after the thermometer has been reversed.

The two thermometers will have the same reading at the time when the mercury column of the reversing thermometer is broken by reversal, and any differences between their readings at any other temperature will be proportional to the difference between this temperature and that at the time of reversal. This ratio is a function of the volume of mercury in the smaller bulb and the capillary of the reversing thermometer. If the thermometers are read simultaneously, a means is provided whereby the temperature at the time of reversal, or in other words the actual temperature of the water, may be computed.

CORRECTION OF REVERSING THERMOMETERS

Two corrections must be applied to the readings of reversing thermometers, namely, the index correction and the temperature-difference correction (the difference between the reading of the reversing thermometer and the auxiliary thermometer).

The index correction, I, is determined by the actual calibration of the thermometer at different temperatures and is dependent solely on the thermometer reading. The correction arises from the slight irregularities in the capillary tube of the thermometer. Many of the reversing thermometers in use have been calibrated by the United States Bureau of Standards, the Physikalisch-Technische Reichsanstalt (P.T.R.), or the National Physical Laboratory (United Kingdom). Upon calibration, these laboratories furnish certificates giving the corrections necessary for several readings of the thermometer. This correction, or index correction, must be added or subtracted. Upon testing reversing thermometers, these laboratories may subject them to a pressure test and the certificate of calibration may bear a phrase: "The action of this instrument was found to be satisfactory after being submitted to a pressure of three tons per square inch." Such a statement indicates that the thermometer may be used down to depths approximately of 4,500 meters without fear of crushing the thermometer by hydrostatic pressure.

The temperature-difference correction is a correction made for the expansion of mercury in the main thermometer and is a function of the amount of mercury in the smaller bulb and the capillary tube; the difference in the temperatures of the main thermometer and the auxiliary thermometer and the nature of the glass comprising the thermometer. If a thermometer is reversed in a layer of cold water and then brought to the surface through a layer of warm water, the mercury in the bulb and capillary of the main thermometer will expand and thus the reading of the main thermometer must be corrected for this expansion. In order to do this, the volume of the thermometer bulb up to the reading of 0° on the capillary must be known and such volume, designated as the degree volume, is given on each thermometer. The total temperature correction, $\pm T$, may be calculated from the following formula:

$$\pm T = E + I$$

where $\pm T$ is the total correction, E the temperature-difference correction, and I the index correction.

$$E = \left[\frac{(T' - V_0)\ (T' - t)}{K}\right]\left[1 + \frac{(T' + V_0)\ (T' - t)}{K}\right]$$

T' = Reading of the main thermometer after reversal.

t = Reading of the auxiliary thermometer after reversal.

V_0 = The degree volume of the thermometer, or the volume of mercury in the thermometer at 0°C.

K — A constant expressing the relative thermal coefficient of mercury and the glass of which the thermometer is made.

The constant K is a function of the quality of the glass comprising the thermometer. Most of the reversing thermometers in use are from Jena glass 59^{iii} or Jena 16^{iii}. For Jena 59^{iii}, $K = 6{,}100$, and for Jena 16^{iii}, $K = 6{,}300$.

Substitution of $K = 6{,}100$ in the above equation reduces it to

$$E = [0.000164\ (T'' - t)\ (T + V_o)]\ [1 + 0.000164\ (T' + V_o) + 0.000164\ (T' - t)]$$

The temperature-difference correction, E, may be ascertained directly from the tables by knowing the values for T', t, and V_o. The true temperature T^o may be found from the equation

$$T^o = T' + \triangle T$$

Illustration: The main thermometer reads 11.00°C, the auxiliary thermometer, 21.0°C, and the degree volume of the main thermometer is 89°C.

$$(T' - t) = -10 \qquad (T' + V) = 100$$

Reference to the table shows that E is -0.167°C. and for most practical purposes becomes -0.17°C. The index correction, found by the calibration of this thermometer is $+.02$°C. The total correction is

$$\triangle t = -.17^o + .02^o = -.15^o$$

and the true temperature

$$T^o = 11.00 - .15 = 10.85^o$$

If a great number of temperatures have to be corrected, it is advisable to construct graphs for this purpose. A detailed description for the construction and use of such graphs is given by Emilsson (1954).

Notes on Form 2. - Thermometer arrangement sheet

A thermometer arrangement sheet is prepared in duplicate before every cruise or when the arrangement is changed during the cruise.

When a thermometer fails to function properly and is replaced, a new arrangement sheet must be completed.

(c)/(d) State the date when the sheet is prepared and the name of the arranger.

(b)/(e) Give the numbers of stations and the dates where and when this arrangement is used.

FORM 2. - THERMOMETER ARRANGEMENT SHEET

(*a*) Cruise No.	(*b*) Stations No.	to No.	(*c*) Date prepared	(*d*) Prepared by
			(*e*) Date used	to

1	2			3				(*f*)	(*g*)
Nansen bottle No.	Left thermometer			Right thermometer				Arrangement changed by	Date and hour
	2.1 P. No.	2.2 V_o	2.3 I	3.1 U. No.	3.2 V_o	3.3 I	3.4 1/Q m Factor	(*h*) checked by	(*i*) Vessel dates
								j Remarks	

(*f*)/(*g*) Indicate the date and hour when this arrangement is changed and a new sheet is prepared.

2.1 P. No. - Number of protected thermometer.

3.1 U. No. - Number of unprotected thermometer.

2.2/3.2. V_o - The mercury volume at 0°C. (Obtained from the thermometer calibration sheet.)

2.3/3.3 I - Index correction of the main thermometer scale. (Obtained from the thermometer calibration sheet.)

3.4 1/Q m - The "pressure factor" for unprotected thermometers.

THE FUNCTION AND CARE OF REVERSING THERMOMETERS

By observing the breaking point of the mercury column in the main thermometer, namely at the top in the coiled end of the capillary where it joins the small dead arm, it is possible to ascertain whether or not the thermometer is in proper condition.

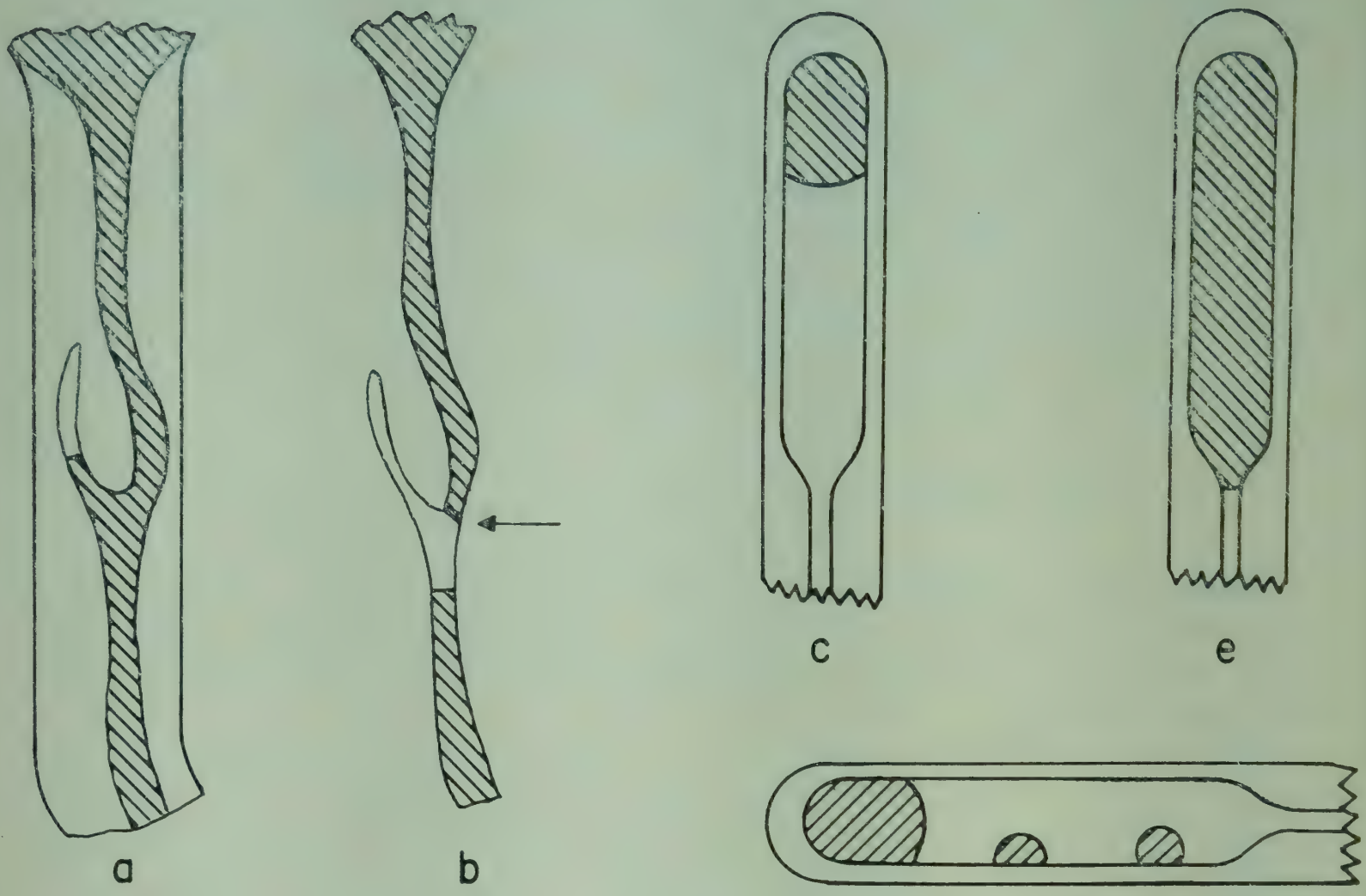
When the thermometer is held in a vertical position with the large bulb at the bottom, there should be no air in any part of the capillary. Upon reversing the thermometer, so that the large bulb is at the top, the mercury should break at the point shown by the lower arrow in (b) (Figure 12). Observation is facilitated by the use of a magnifying glass. Upon repeating this operation very slowly, the mercury must first run out of the side arm as shown in (a). During this process, care should be taken not to touch the bulb with the hand, for a temperature change makes an exact observation of the breaking point impossible. The separated column of mercury, which breaks at the side arm, runs downward into the smaller bulb and graduated capillary of the main thermometer and thus corresponds to the temperature prevailing at the time of reversal. If, after the breaking of the mercury thread, the thermometer is reversed to its original position, the mercury must run out of the smaller bulb and capillary and join the mercury in the main bulb at the dead arm. Under such conditions it may be assumed that the thermometer is functioning properly.

IMPROPER FUNCTIONING OF THE REVERSING THERMOMETER

As a result of improper handling, such as in transportation, sudden blows, or remaining in a horizontal position for a protracted period of time, the mercury may no longer form a connected thread and behave as described above. The difficulty then observed may fall into one of the three categories as follows (Figure 12).

(a) *Mercury remains in the upper portion of the smaller bulb*

After reversing the position of the thermometer so that the large bulb is below, some of the mercury may remain in the smaller bulb. This condition is illus-



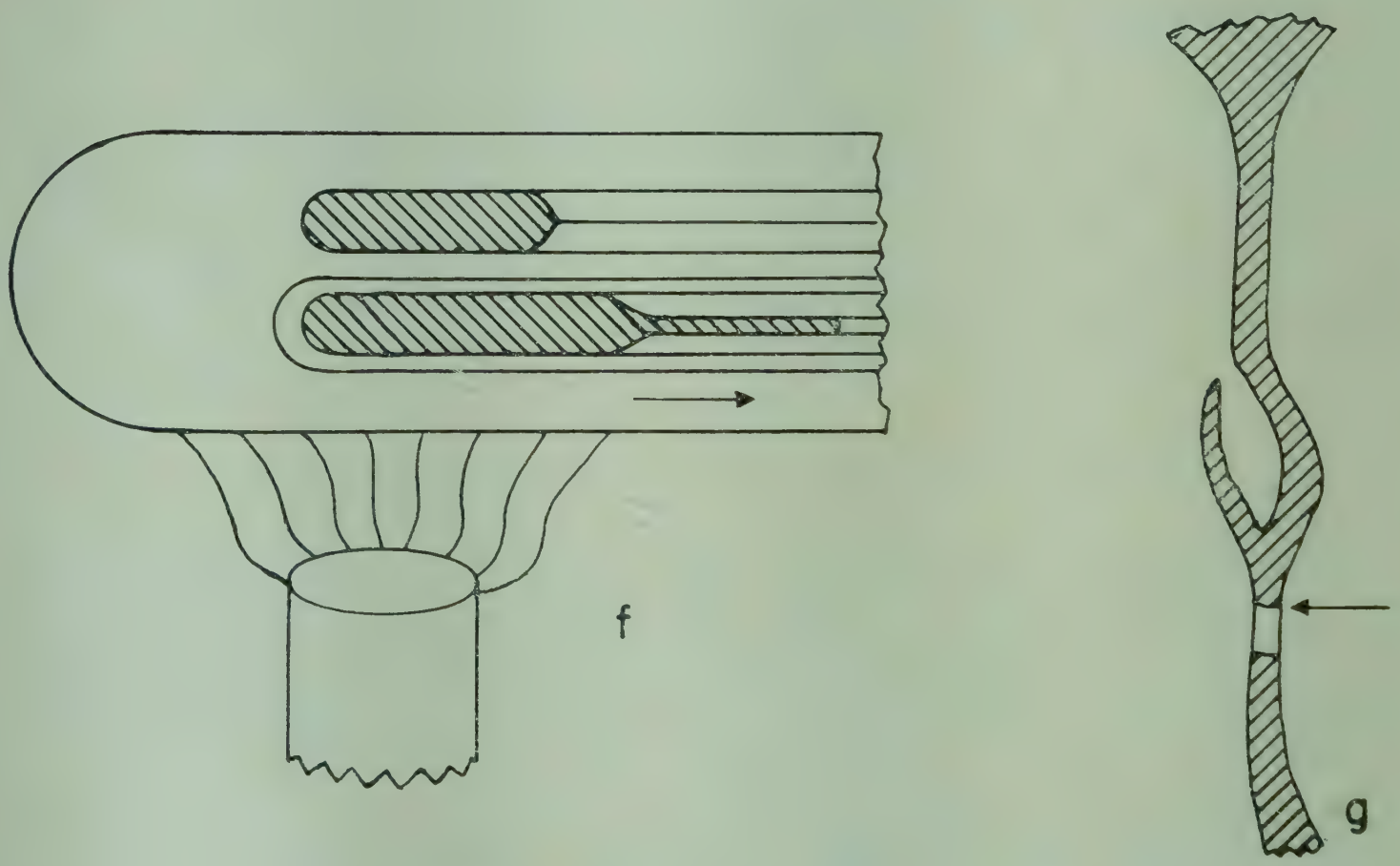


FIGURE 12. - Care of reversing thermometers

trated in (c). In many cases, it is sufficient to reverse the thermometer again. When the mercury flowing from the large bulb is united with that which remained in the smaller bulb and the thermometer is again turned to its original position, proper functioning of the mercury is observed.

If this does not occur and part of the mercury still stays in the smaller bulb, a small particle of air, generally observable with a magnifying glass, is the cause of the difficulty. To remedy this situation, hold the thermometer by the large bulb in a horizontal position in the right hand and then gently tap the other end of the thermometer in the palm of the left hand until several globules of mercury separate in the small bulb as shown in (d). The thermometer is then carefully inverted so that the mercury runs into the smaller bulb. As soon as it touches the small globules that have been separated, turn the thermometer again to its original position. The separated globules are thus drawn into the main bulb. Several more globules are again separated and the process repeated until all the mercury is reunited.

Under no circumstances hold the thermometer in a vertical position with large bulb downward and jar by tapping. If this is done, the air bubble may eventually be forced into the dead arm of the lower capillary and the thermometer will be ruined.

(b) *Mercury remains in smaller bulb, breaking at capillary*

This undesirable situation is shown in (e). To remedy it, hold the thermometer in a horizontal position and warm the smaller bulb over a small bunsen flame, as illustrated in (f), constantly rotating the thermometer. The mercury in the auxiliary thermometer rises at the same time and care must be exercised in order that no breaking of the mercury thread occurs. During the heating, the thermometer should occasionally be brought to a vertical position to see if heating has been sufficient so that the mercury runs down the capillary to the large bulb. If this occurs, the small air bubble is pushed downward into the main bulb. Examination may show that the mercury thread breaks at the proper place and that the thermometer functions normally. However, before it is used, the zero point should be checked by immersing the instrument in ice.

If the air bubble is in the looped capillary or the mercury thread does not break at the proper place, the procedure recommended below should be followed.

(c) *The mercury thread does not break at proper place*

Such a situation is illustrated in (g). To correct this defect the thermometer is placed in a vertical position, large bulb downward, and when a continuous mercury thread has formed cool the bulb to a very low temperature, immersing, if necessary, in a salt-ice mixture. Holding the thermometer at the looped capillary, quickly reverse it with a jerk. The thread will break at the air bub-

ble and may also break at the usual place. After the smaller bulb is filled with the mercury, turn the thermometer to a horizontal position and warm the larger bulb slowly and carefully to about 60°C. The air bubble is driven forward. Return thermometer to original position and cool. This process of alternate cooling and heating is continued until the air bubble is above the mercury. When the thermometer begins to function normally again, it is best to check the zero reading by inserting in melting ice.

2.3.1.3.4 *Measurement of temperature with the bathythermograph*

(By John P. Tully. Extracted from: *Manual of oceanographic methods.* (1950) Nanaimo, B.C., Canadian Joint Committee on Oceanography, Pacific Oceanographic Group. Mimeo.)

MECHANISM

Temperature device

Forty-five ft (13.7 m) of copper capillary tube operating a Bourdon tube.

Pressure (depth) device

Sylphon bellows with slide carriers, spring tension 320 lbs (145 kg), compresses spring 1 in.; 450 ft (137 m) depth = 225 lbs (102 kg), compresses spring 0.7 in. (18 mm).

Recording device

A smoked glass slide is carried in an adapter fitted rigidly to the sylphon bellows, and moves with pressure on the long axis of the BT. A stylus fitted to the Bourdon tube moves with temperature on transverse axis.

The resultant motion is recorded by the scratch left by the stylus on the smoked glass slide.

Accuracy

A difference of 0.1°F (0.05°C) can be recognized in the temperature-depth curve, if the instrument and slides are good. Normally 0.2°F (0.1°C) precision is expected and obtained. The absolute accuracy depends on the accuracy of the index observation.

Slides

These are smoked glass (1 in. × 1 3/4 in.) (25 mm × 44 mm) made by moistening the glass with oil and smoking in the yellow flame of an oil lamp.

Calibration grid

Each instrument is placed in a pressure tank and a series of calibrations is made at known temperatures and pressures. This is amplified to show depths at 10 ft (3 m) intervals, and temperature at 1°F (0.5°C) intervals. The instrument should be recalibrated every time an adjustment is made. Naval Research Establishment, H.M.C. Dockyard, Halifax, Woods Hole Oceanographic Institution at Woods Hole, Massachusetts, and Scripps Institution of Oceanography at La Jolla, California, are equipped to calibrate instruments.

RIGGING

The BT is secured to a sounding line (1/32 in. or 1/16 in.) (0.8 mm or 1.6 mm) galvanized steel sounding line, or equivalent. The line is led from a sounding machine (Kelvin), or suitable winch, over a travelling block on a boom leading well clear of the ship's sides.

PROCEDURE

Preserving the slide

First make index notations on the slide and dip it in fresh water, and finally in amyl-acetate lacquer, and dry.

Preserving records

The temperature record may be examined at once by placing it over the standard grid in the viewer provided. It is customary to make the date permanent by a photographic enlargement of the slide, and its calibration grid, on the back of which all pertinent data are recorded.

2.3.1.4 Calculation of actual depth

A rough estimate of the depths at which the water bottles of a cast are reversed in the sea may be obtained from the wire angle (the angle the wire makes with the vertical) at the sea surface, and the length of wire to each bottle. However, this method assumes that the curvature of the wire below the surface is known, an assumption which is not valid to great depths. The method is satisfactory only for depths of less than 100 meters with large wire angles, and to several hundred meters with angles less than 5°.

The customary method of determining depth of sampling when the wire angle is greater than 5° is by comparing the corrected readings of the protected and unprotected deep-sea reversing thermometers.

The correction of the unprotected thermometer which is used in conjunction with the protected thermometer is a simpler calculation because the temperature of reversal of the latter is known. The correction is determined from:

$$\triangle T = \frac{(Tw - t)\ (T' + V_0)}{K} + I$$

Tw = Temperature of reversal of the protected thermometer.
t = Temperature of the auxiliary thermometer of the unprotected thermometer.
T' = Reading of the unprotected thermometer.
V_o = Degree volume of the unprotected thermometer.
K = 6100
I = Index correction.

From the corrected readings of the protected and unprotected thermometers, the depth at their reversal may be computed from the equation:

$$D = \frac{(Tu - T)}{Qd}$$

Where D = Depth in meters.
Tu = Corrected reading of unprotected thermometer.
T = Corrected reading of protected thermometer.
Q = Pressure-constant of the unprotected thermometer.
d = Mean specific gravity of the water column above the thermometer, and is obtained from the chlorinity determinations and the temperatures.

The pressure-constant of the unprotected thermometer is the change in degrees in corrected reading caused by a change in pressure of 0.10 kilograms per square centimer. The constant is of the order of magnitude of 0.01 and is ascertained from the thermometer certificate which, however, usually gives the degree change in ten times the value of Q, or in other words, the degree change in readings per kilogram per square centimer change in pressure. In general, one meter in depth is equivalent to a change 0.01°C for the corrected readings.

Illustration

The corrected reading of the protected thermometer is 1.95°; of the unprotected thermometer 39.82°; the average density of the water, computed from chlorinity and temperature determinations made at twelve different

TABLE 1. - LENGTH IN METERS OF CABLE REQUIRED TO REACH CALCULATED DEPTHS AT CERTAIN WIRE ANGLES

Calculated depth (in meters)	Wire angle												
	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°
50	53	55	58	61	65	71	78	87	100	118	146	193	288
100	106	110	116	122	130	141	156	174	200	237	292	386	576
150	160	165	173	183	196	212	233	261	300	355	439	580	864
200	213	221	231	244	261	283	311	349	400	473	585	773	1152
250	266	276	289	305	326	354	389	436	500	592	731	966	1440
300	319	331	346	366	392	424	467	523	600	710	877	1159	1728
350	372	386	404	427	457	495	545	610	700	828	1023	1352	2016
400	426	441	462	488	522	566	622	697	800	946	1170	1546	2304
450	479	496	520	549	587	636	700	784	900	1065	1316	1739	2592
500	532	552	596	610	652	707	778	872	1000	1183	1462	1932	2880
550	585	607	635	672	718	778	856	959	1100	1301	1608	2125	3167
600	638	662	693	733	783	848	934	1046	1200	1420	1754	2318	3455
650	692	717	751	794	848	919	1011	1133	1300	1538	1901	2512	3743
700	745	772	808	855	914	990	1089	1220	1400	1656	2047	2705	4031
750	798	827	886	916	979	1060	1167	1307	1500	1774	2193	2898	4319
800	851	882	924	977	1044	1131	1245	1395	1600	1893	2339	3091	4607
850	904	938	982	1038	1109	1202	1323	1482	1700	2011	2485	3284	4895
900	958	993	1040	1099	1174	1273	1400	1569	1800	2129	2632	3478	5183
950	1011	1048	1097	1160	1240	1343	1478	1656	1900	2248	2778	3671	5471
1000	1064	1103	1155	1221	1305	1414	1556	1743	2000	2366	2924	3864	5759

Intermediate values can be calculated readily with a slide rule. On the K and E rule set the angle on the S scale (*using the left slanted* figures) opposite the desired depth. Read the length of cable opposite the S index.

depths, is 1.02550. The pressure constant as kilogram per square centimeter, is given as 0.1144. The true depth is

$$D = \frac{39.82 - 1.95}{0.1144 \times 1.02550} = \frac{37.87}{0.1173} = 3{,}228 \text{ meters}$$

According to Whitney (1957) the accuracy of thermometer depth determination is usually within 0.5 percent and is frequently 0.2 percent. Analysis of the factors affecting the accurancy is also given by Whitney.

2.3.1.5 Direct determination of density of sea water

Direct determination of salinity, usually by measuring the density, is sufficient and can be undertaken in cases where great variations occur, as in brackish water. The accuracy is usually in the range of $\pm$ 0.05 $^{o}/_{oo}$ of salinity.

There are several types of Temperature-Salinity-Depth (TSD) recorders. These instruments work on the principle of the changes of electrical conductivity with salinity and temperature. They record the TSD automatically on paper when the instrument is lowered into the water. They can be used only in brackish water and in the upper 100 m.

Salinity determinations are also made by refractometers (Figure 13), but only in brackish water, and the method needs considerable optical practice. The cheapest and simplest method to determine salinity in brackish water is with properly calibrated areometers (Figure 14), the reading of which can be converted to chlorinities and salinities by reference to Knudsen's tables, temperature having been measured.

2.3.1.6 Processing of oceanographic data

Most oceanographic data can be considered as indirect observations and need considerable corrections and processing before they are applied in solving certain problems. Some of the present standard methods are given in the following chapter. Again, the further application of these data is given in the synopsis on fisheries hydrography and in other manuals. The following notes have been extracted mainly from the following publications: LaFond, E.C. (1951) *Processing oceanographic data.* Washington, D.C., U.S. Navy Hydrographic Office. H.O. Pub. No. 614, and *Manual of oceanographic methods.* (1950) Nanaimo, B.C., Canadian Joint Commission on Oceanography, Pacific Oceanographic Group. (Mimeo)

Specific volume and specific volume anomaly

Specific volume (or volume per unit mass) *in situ* in the sea is expressed by the symbol $\alpha_{s,t,p,}$ where the subscripts indicate the salinity, temperature and pressure of the sample.

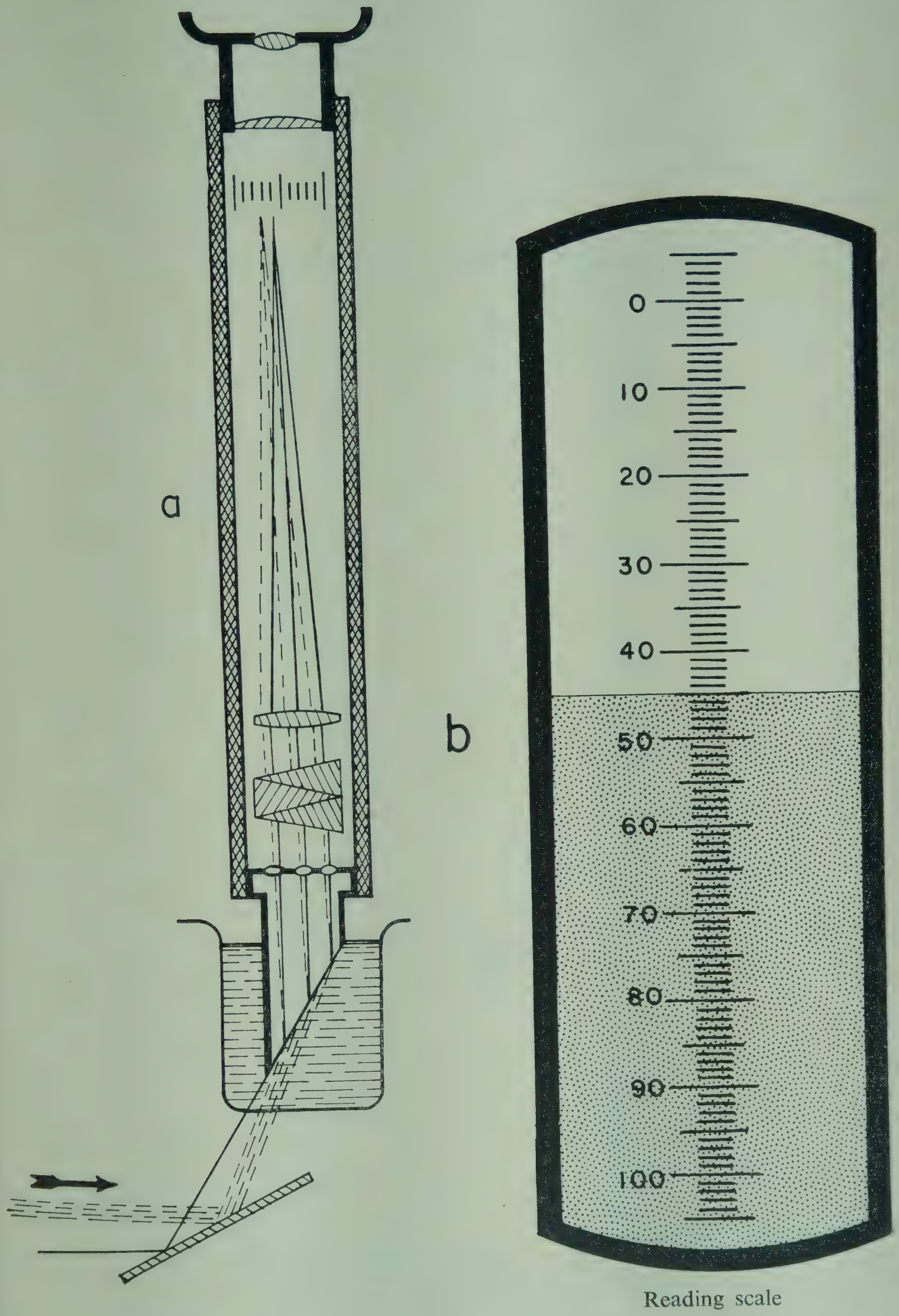


FIGURE 13. - Refractometer

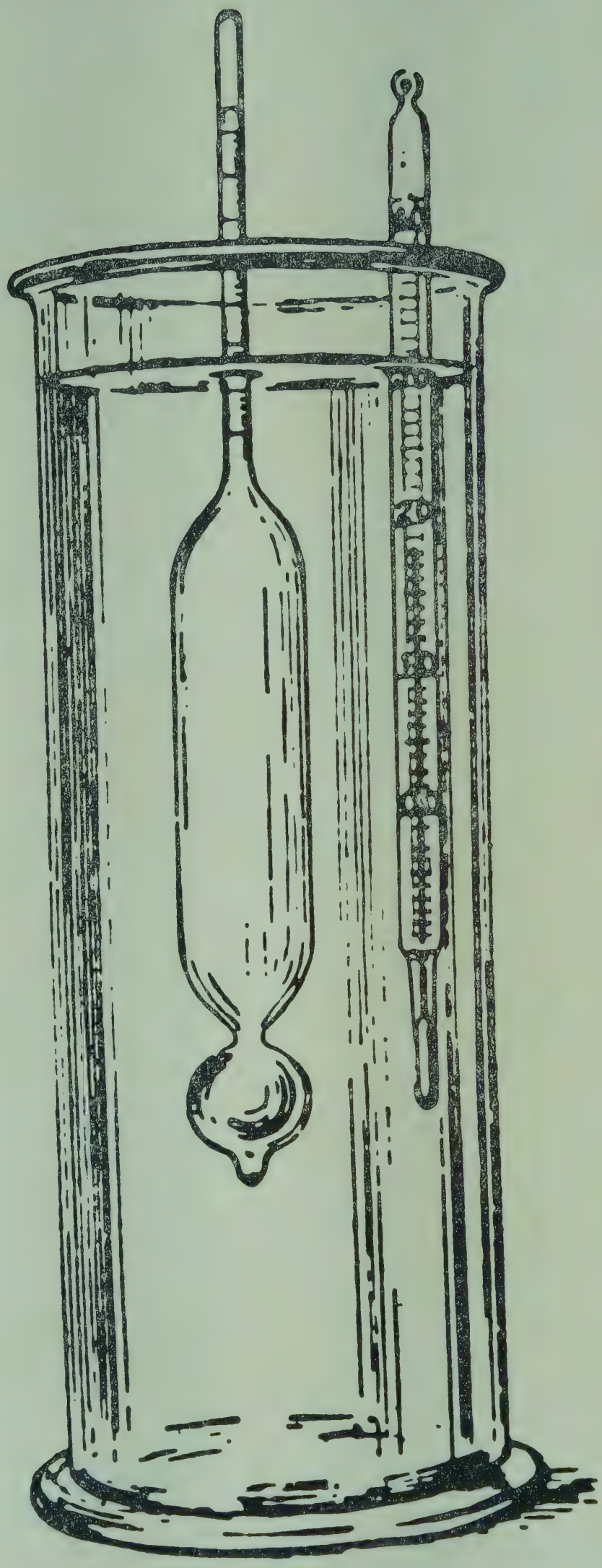


FIGURE 14. - Areometer

Specific volume *in situ* can be computed directly by the following equations developed by V.W. Ekman (Bjerknes and Sandström, 1910).

$$\alpha\, s, t, p = \alpha\, s, t, o - p\alpha\, s, t, o\; 10^{-9} \left(\frac{4886}{1 + 0.0000183\, p} - \right.$$

$$- [227 + 28.33\, t - 0.551\, t^2 + 0.004\, t^3] +$$

$$+ p\, 10^{-4} [105.5 + 9.50\, t - 0.158\, t^2] - 1.5\, p^2\, t\, 10^{-8} -$$

$$- \frac{\sigma\, o - 28}{10} [147.3 - 2.72\, t + 0.04\, t^2 - p\, 10^{-4} (32.4 - 0.87\, t +$$

$$+ 0.002\, t^2)] + \left(\frac{\sigma\, o - 28}{10} \right)^2 [4.5 + 0.1\, t - p\, 10^{-4} (1.8 -$$

$$\left. - 0.06\, t)] \right)$$

The above equation can be evaluated from values of temperature, t (°C); salinity, s (‰), or chlorinity, Cl (‰); and pressure, p (decibars), by means of the following expressions (Knudsen, 1901).

$$s = 0.030 + 1.8050\; Cl$$

$$\sigma\, o = -0.069 + 1.4708\; Cl - 0.001570\; Cl^2 + 0.0000398\; Cl^3$$

$$\sigma\, s, t, o = \Sigma t + (\sigma_o + 0.1324)\, [1 - A_t + B_t\, (\sigma_o - 0.1324)]$$

where,

$$\Sigma t = -\left[\frac{(t - 3.98)^2}{503.570} \right] \left[\frac{t + 283}{t + 67.26} \right]$$

$$A_t = t\, (4.7867 - 0.098185\, t + 0.0010843\, t^2)\, 10^{-3}$$

$$B_t = t\, (18.030 - 0.8164 + 0.01667\, t^2)\, 10^{-6}$$

and,

$$\alpha\; s, t, o = \frac{1}{\rho\; s, t, o} = \frac{1}{1 + 10^{-3}\, \sigma\; s, t, o}$$

The error in the specific volume calculated from the above expressions is believed to be ± 0.00001 for pressures of 1,000 decibars, and ± 0.0001 for 10,000 decibars.

The more practical method of computing specific volume is by expressing it as a known specific volume under given conditions, plus a series of correction terms for the dependent variables of temperature, salinity, and pres-

sure. These terms may be grouped, computed, and added as follows to give specific volume *in situ*:

$$\alpha_{S,\,t,\,p} = (\alpha_{35,0,0} + \delta_p) + (\delta_S + \delta_t + \delta_{S,\,t}) + \delta_{S,\,p} + \delta_{t,\,p} + (\delta_{S,\,t,\,p})$$

In the first two terms, $\alpha_{35,0,0}$ is a constant (0.97264) and δ_p represents the effect of pressure at standard salinity and temperature (35‰ and O°C). The sum of the two terms gives a standard specific volume:

$$\alpha_{35,0,0} + \delta_p = \alpha_{35,0,\,p}$$

The values of the standard term $\alpha_{35,0,\,p}$ are given in tables, e.g. LaFond, 1951.

The next three terms of the expansion depend only upon salinity and temperature, and are combined to form the single term $\triangle_{s,t}$; that is, $\delta_S + \delta_t + \delta_{S,t} = \triangle_{s,t}$. This temperature-salinity term of the anomaly of specific volume (discussed below) is found from values of temperature and salinity by means of tables or graphs, as will be illustrated presently (Sverdrup, 1933). If σ_t has already been computed, $\triangle_{s,t}$ may be found from the formula,

$$\triangle_{s,t} = 0.02736 - \frac{10^{-3}\,\sigma_t}{1 + 10^{-3}\,\sigma_t}$$

or by the tables (LaFond, 1951).

The salinity-pressure term, $\delta_{S,p}$, and temperature-pressure term, $\delta_{t,p}$ of the anomaly of specific volume are found from tables or graphs. The final term, $\delta_{S,\,t,\,p}$, is so small that it may be neglected.

The sum of the terms $\triangle_{s,\,t}$, $\delta_{S,\,p}$, and $\delta_{t,\,p}$, constitute the anomaly of specific volume from the standard, $\alpha_{35,\,0,\,p}$, and are designated by the single symbol δ. Thus,

$$\delta_S + \delta_t + \delta_{S,\,t} + \delta_{S,\,p} + \delta_{t,\,p} = \triangle_{s,\,t} + \delta_{S,\,p} + \delta_{t,\,p} = \delta$$

For current calculations, the variation in specific volume along an isobaric surface is required. Since pressure is constant along any given isobaric surface, the term δ_p is a constant as well as $\alpha_{35,0,0}$. It is sufficient, therefore, to calculate the specific volume anomaly, δ, since the standard term contributes nothing to variation in specific volume along an isobaric surface.

However, if the total specific volume *in situ* is desired, it is obtained by adding the standard term and the anomaly, $\alpha_{S,\,t,\,p,} = \alpha_{35,0,\,p} + \delta$.

For calculating the anomaly, graphs or tables may be used, as mentioned above. The term $10^5\,\triangle_{S,\,t,}$ is given in tables for values of temperature and salinity (e.g., LaFond, 1951). The other terms $10^5\,\delta_{t,\,p}$ and $10^5\,\delta_{S,\,p}$ are given in tables as well. Such tables have also been put in graphical form (Sund, 1926; Callaway, 1950).

To obtain sufficient accuracy the graphs should be of such a size that 1 inch along the co-ordinate axes represents 0.0001 of each of the terms of the anomaly or $0.1^{o}/_{oo}$ of salinity. A number of large charts are required to cover the normal range of the variables.

Density and "Sigma-T"

Density (or mass per unit volume) *in situ* is the reciprocal of the specific volume *in situ*:

$$\rho s, t, p = \frac{1}{\alpha_{S, t, p}}$$

The density *in situ*, $\rho_{S, t, p}$, may be determined by first calculating the specific volume *in situ* from the equations and tables of the preceding pages and then taking the reciprocal. For example, if at a given salinity, temperature, and pressure the specific volume is 0.96996, the density

$$\rho s, t, p = \frac{1}{0.96996} = 1.03097$$

Another way to express the density is by the symbol $\sigma_{S, t, p}$. By definition, $\sigma_{S, t, p} = 10^{3} (\rho_{S, t, p} - 1)$. Thus, if $\rho_{S, t, p} = 1.03097$, $\sigma_{S, t, p} = 30.97$. This expression has the advantage that the numerical value contains fewer digits and consequently is easier to handle.

It is common practice to abbreviate the expression $\sigma_{S, t, o}$ to only σ_{t}, which represents the density of water of given salinity and temperature at surface pressure. "Sigma-T" is widely used to describe the sea and has the significance that motion along σ_{t} surfaces involves little change in energy, and therefore, mixing of water masses tends to take place along these surfaces. By definition,

$$\sigma_{t} = 10^{3} (\rho_{S, t, o} - 1)$$

Thus, if $\rho_{S, t, o} = 1{,}02727$, $\sigma_{t} = 27.27$. In like manner, $\sigma_{o} = 10^{3} (\rho_{S, o, o} - 1)$.

σ_{t} depends only upon salinity and temperature, and may be found directly from values of these variables, either graphically or by means of tables. If $\triangle_{S, t}$ has been calculated, σ_{t} may be read directly from tables (LaFond, 1951). Other aids in the determination of σ_{t} are graphs.

If the temperature is 4.55°C. and salinity is 34.40‰, σ_{t} will equal 27.27.

Several tables for σ_{t}, have been compiled by various people including LaFond (1951), McEwen (1929), Matthews (1932), Fleming (1939), Ennis (1944), and Bumpus and Martineau (1948). These tables are based on Knudsen's equations given on the preceding pages.

Relative currents

The current along an isobaric surface is essentially a function of the geopotential (or dynamic) slope of the isobaric surface. If, at some depth, motion may be assumed negligible and an isobaric surface essentially level, the dynamic slope of an upper isobaric surface may be found from the variation of specific volume along the isobaric layer. Thus the current at the upper surface relative to any possible current at the lower surface is determined.

For each oceanographic station of a network of stations, the dynamic thickness of the isobaric layer may be calculated by means of the hydrostatic equation,

$$D_2 - D_1 = \int_{p_1}^{p_2} \alpha \, dp$$

where,

$D_2 - D_1$ = dynamic thickness of the isobaric layer,
α = specific volume,
dp = pressure interval.

Since $\alpha = \alpha 35, 0, p + \delta$, the total dynamic thickness of the layer may be considered composed of the dynamic thickness of the layer of standard specific volume from standard. Thus,

$$D_2 - D_1 = \int_{p_1}^{p_2} \alpha 35,\ 0,\ p dp + \int_{p_1}^{p_2} \delta \, dp =$$

$$= (D_2 - D_1) \text{ standard} + \triangle D.$$

The dynamic thickness of the standard layer is the same at every station. Therefore the differences in dynamic height between stations are completely given by the differences in the increments, $\triangle D$, and it is only necessary to calculate $\triangle D$ at each station, using the formula $\triangle D = \int_{p_1}^{p_2} \delta \, dp$.

In practice, meters of depth are substituted for decibars of pressure in the equation. The insignificant error in $\triangle D$ introduced by this substitution is negligible, amounting to 1 percent or less.

Procedure in computing $\triangle D$ at each station is as follows. The specific volume anomaly, $\bar{\delta}$, at each depth is calculated by one of the methods previously outlined. The mean specific volume anomaly, $\bar{\delta}$, for each depth interval may be determined by averaging the two bounding values. Multiplying this mean value, $\bar{\delta}$, by the depth interval (which corresponds essentially to the pressure interval between depths) gives the anomaly of dynamic height, $\triangle D$, for each small depth (or pressure) layer. The required total $\triangle D$ for each station is obtained by adding the anomalies of dynamic height, $\triangle D$, from the selected reference level of no motion to the level at which relative currents are to be computed.

The final step in computing the current passing between two stations is to equate the forces acting along the sloping isobaric surface between stations, and solve for the velocity. The force of gravity acting downslope is expressed by the difference in the anomalies of dynamic height at the two stations divided by the distance between stations. Since the computation of $\triangle D$ was based upon pressure in decibars, rather than the standard unit centibars, a factor of 10 is necessary to convert the expression to meter-ton-second units. Equating this force to the expression for the Coriolis force acting upslope gives

$$\frac{10\ (\triangle D_A - \triangle D_B)}{L} = V\,2\,\omega \sin \varnothing$$ (Sandström and Helland-Hansen, 1903), where,

$\triangle D_A - \triangle D_B$ = difference in the anomalies of dynamic height at stations A and B, in dynamic meters,

L = distance between stations in meters,

V = relative current velocity normal to a line joining the two stations, in meters per second,

ω = angular velocity of the earth, equal to 0.729×10^{-4} radians per second,

$\varnothing$ = mean latitude between stations.

Solve the equation for the velocity: $V = \dfrac{10\ (\triangle D_A - \triangle D_B)}{L\,2\,\omega \sin \varnothing}$

To simplify the computation of velocity in meters per second, the factor $\dfrac{10}{L\,2\,\omega \sin \varnothing}$ is given in tables for unit values of L and for each degree of latitude. Conversion factors are also given in tables for various units of V and L. There are graphical aids in the calculation of current velocity from dynamic height differences (LaFond, 1951).

The usual graphical way not only of measuring but also presenting current data for analysis is by the construction of charts showing the dynamic topography of one or more isobaric surfaces relative to a reference surface, which is assumed to be level. The anomaly of dynamic height, $\triangle D$, between the reference surface and the selected isobaric surface above is plotted on a base chart at each oceanographic station, and contours of equal values of dynamic height anomaly are drawn.

Since the force of gravity acts downslope normal to the contours, and the balancing Coriolis force is always normal to the velocity, it follows that the current flows along the contours of dynamic topography. The surface slopes upward to the right of the current in the northern hemisphere, to the left of the current in the southern hemisphere.

When the contours are drawn at equal intervals of dynamic height anomaly, the velocity of the current is inversely proportional to the distance between contours. An insert graph is normally given on the chart to relate dynamic height contour spacing to current speed. Charts showing the dynamic topography of an isobaric surface relative to a lower isobaric surface thus not only present a complete picture of motion at the upper surface relative to any motion at the lower surface, but eliminate the need for numerical calculation of the components of currents between stations from dynamic height differences.

Certain limitations to the accuracy of the current calculations outlined above should be borne in mind: (1) Currents deduced are relative to any unknown current at the reference level rather than absolute values. (2) Accelerations have been neglected; if currents are changing, the results of the calculations are less valid. (3) Frictional forces have been neglected. (4) Observations taken at different times at the different stations have been assumed simultaneous. In some areas the influence of internal waves (LaFond, 1949) and tidal influence on dynamic height are taken into account. These limitations may, however, be largely offset by the familiarity with a region which comes with repeated observations (provided conditions are quasi-permanent).

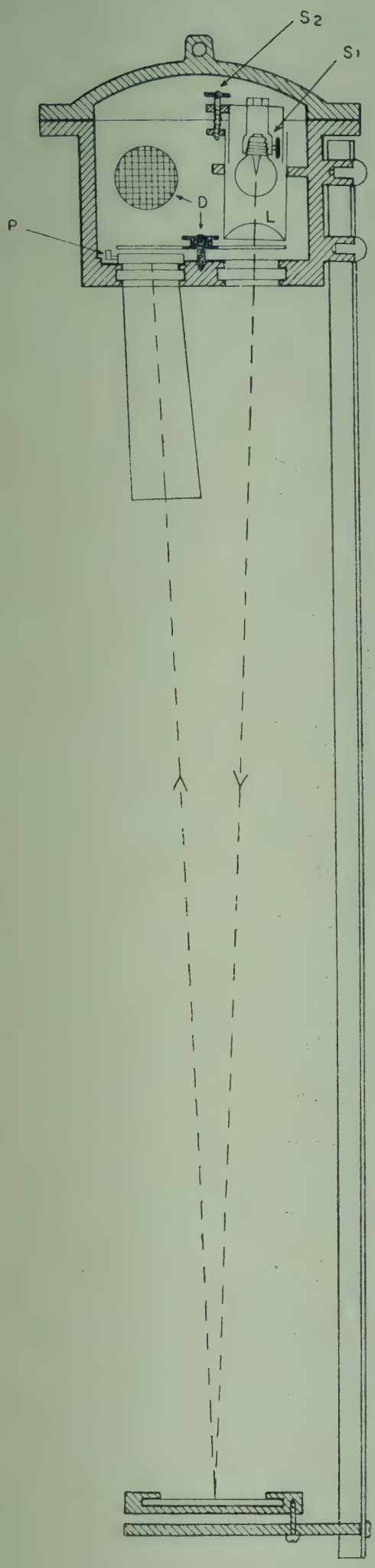
2.3.1.7. Turbidity measurements

Measures of turbidity are an indication of the amount of suspended matter, including plankton, in the sea water. Changes of turbidity often indicate changes of water masses and convergence lines.

Turbidity measurements are made either visually or with optical instruments. The white, 30-35 cm diameter, Secchi disk is used for visual estimates. It is lowered into the water, on the shadow side of the vessel, attached to a line marked in meters or feet. The depth at which the disk disappears from sight is recorded. The disk should be moved slowly up and down at this depth in order to determine the exact depth of disappearance. The depth is usually converted into extinction coefficients: $X = 1.7/D$ where X = extinction coefficient; D = maximum depth of visibility of Secchi disk (in m).

The extinction coefficient can also be measured with electrical extinction meters lowered into the water (Figure 15). These instruments have an electric light in one end and a photocell at a distance of 60 cm - 2 m at the opposite end. The readings of the photocell are converted either into the percentage of light intensity as compared with clean water, or into an extinction coefficient. The latter should be recorded. These instruments need careful attention and special study. For example, the light source must be constant and the window clean and dry on the inside; drying chemicals (e.g., silica gel) are used for this purpose.

Quantitative and qualitative study of suspended matter in sea water can also be made by taking water samples from different depths. The samples must be analyzed immediately on arrival on board. For a more detailed description of these methods with photometers, spectrophotometers or more often with Tyndall's apparatus (Figure 16) see references at the end of this Section.



← FIGURE 15. - Plan of the transparency-meter

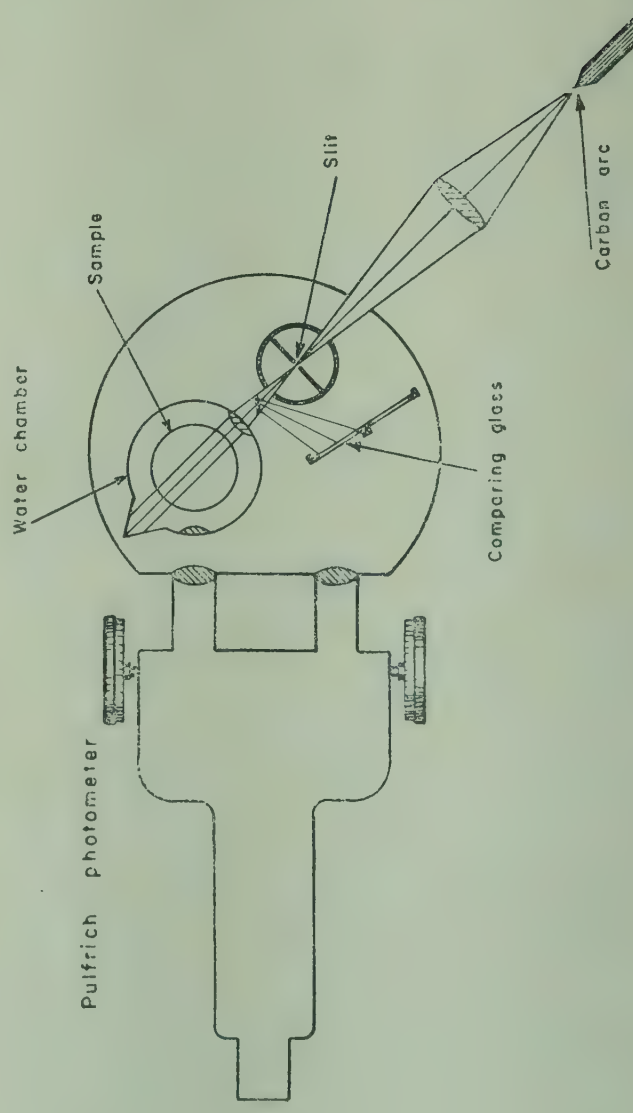


FIGURE 16. - Tyndall meter →

FORM 3. - PRIMARY OCEANOGRAPHIC DATA SHEET

(*a*) Cruise	(*b*) Station	(*c*) Latitude	(*d*) Longitude	(*e*) Wind force	(*f*) Sonic depth	(*g*) Color of the sea	(*h*) Cast	(*i*) Wire angle	(*j*) Start (GCT)	(*k*) Messenger		
										(*l*) Down (GCT)	(*m*) Up (GCT)	(*n*) In (GCT)

(*o*) Vessel (name)	(*p*) Date (GCT)	(*q*) Sea	(*r*) Bottom type	(*s*) Trans-parency	(*t*) BT Slide No.	(*u*) Observer

1 Des. Depth m	2 Meter wheel	3 Thermo-metric depth	4 Wire depth	5 Sample bottle No.					6 Sampler (Nansen bottle) No.	7 Thermom-eter Left		8 Thermom-eter Right		9 Remarks
				5.1 Cl °/₀₀	5.2 02	5.3 PO 4	5.4	5.5		7.1 Main	7.2 Aux.	8.1 Main	8.2 Aux.	

Notes on Form 3. - Primary oceanographic data sheet

This sheet is completed (with a carbon copy) for every hydrographic station at which water samples from below surface are taken.

(*c*)/(*d*). Instead of latitude and longitude a descriptive position or a number or letter for routine stations can be given in coastal waters if the exact position of the station is clearly indicated on the chart and in the Cruise and Station log, but only provided these other records are easily accessible to those using this sheet.

(*e*). Give wind force only. Other meteorological data are entered in the meteorological data sheet, which is usually kept on the bridge.

(*f*). Give the depth obtained as with the echo-sounder (or by other sounding). If this is not possible, enter the depth as indicated on the sea chart.

(*g*). State the color of the sea according to the Forel scale.

(*h*)/(*i*)/(*j*)/(*k*)/(*l*)/(*m*)/(*n*). Give the number of hydrographic casts, wire angle before sending the messenger for closing the bottles and the times for starting the cast, when messenger is sent down, when the heaving up is started and when all bottles are in.

(*q*). Give the state of the sea, coded.

(*r*). Give the coded description of sediment or type of bottom if sample obtained, or the type of bottom if otherwise ascertained (e.g., from sea charts, sediments fastened on weight, etc.).

(*s*). State the transparency, as obtained by the Secchi disk.

2. Give the meter wheel readings when lowering the cast.

3. Thermometric depth as determined later from the difference between the unprotected and protected temperature readings.

4. Wire depth as determined from the meter wheel reading and wire angle. (See Table 1.)

5. Give the numbers of the sample bottles.

6. Give the numbers of Nansen bottles (or other water samplers used).

7/8. Enter the readings of the thermometers.

9. Remarks should include any misbehavior of thermometers and other items of interest. The numbers of salinity boxes, amount of roll of vessel, etc., should also be noted here.

Form 4. - Oceanographic summary sheet

(*a*) Vessel ..... (*b*) Station ..... (*c*) Date-Time ..... to .....

(*d*) Latitude ..... (*e*) Longitude ..... (*f*) Depth ..... (*g*) Observer .....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Serial	Calc.	Observed		Interpolated													
No.	P	T°C	S°/₀₀	D	T°C	S°/₀₀	σ_o	σo-σt	σt	$\Delta s, t$	$\delta t, p$	$\delta s, p$	δ	δ	Δ D	Σ D	

Notes on Form 4. - Oceanographic summary sheet

Make entries in the heading as indicated, using the name of the vessel from which the samples were taken and the serial station number. Indicate time zone on which times are based (Z for Greenwich; + values for zones west, and — values for zones east of Greenwich). Report latitudes and longitudes in degrees and minutes, with decimal fractions of a minute when such are significant. Report depths in meters. The columns have the following significance:

1. Serial number of observation.

2. Depth, calculated using meter wheel readings, wire angle and protected and unprotected thermometer readings.

3. Temperature for depth given in column 2 as obtained from protected thermometer, fully corrected.

4. Salinity for depth given in column 2.

5. Standard depths for purposes of computation.

6. Temperatures at standard depth as obtained by interpolation from temperature vs. depth curve based on values given in columns 2 and 3.

7. Salinities at standard depths as obtained from salinity vs. depth curve based on values given in columns 2 and 4. (The use of chlorinities in preference to salinities awaits expansion of suitable tables for use in interpolation.)

8. As normally defined $O_o = (C_o — 1)\ 10^3$ where C_o is the density of the water of the given chlorinity at 0°C under atmospheric pressure. In this column, however, the factor 10^5 is used rather than 10^3 in order to drop the decimal point. Obtain from Knudsen's tables.

9. $D = O_o — O_t$ as obtained from Knudsen's tables or expansion of same (cf. expanded table of Thompson and Robinson). As in column 8 the factor of 10^5 is used rather than 10^3 in order to drop the decimal point.

10. $O_t = (\sigma_{S,\, t,\, o} — 1)10^3$ where $\sigma_{S,\, t,\, o}$ is the density of the water of given salinity, and t_0C under atmospheric pressure. Factor of 10^5 rather than 10^3 is used to permit dropping decimal point. O_t is obtained from columns 8 and 9 or preferably directly from columns 6 and 7 where suitable tables are available to cover temperature-salinity range [see Donald J. Matthews. (1932) *Tables of the determination of density of sea water under normal pressure, Sigma-t.* Cons. int. Explor. Mer. 59 p.; and E.C. LaFond. (1951)

Processing oceanographic data. U. S. Navy Hydrographic Office. 114 p. H.O. Pub. No. 614].

11. Values of $10^5 \triangle_{s,t}$ as obtained from O_t, column 10, using Table III, appendix, p. 1055 of *The oceans*.

12. 10^5 $C_{t,p}$ as obtained from Tables Va and Vb of *The oceans* (appendix, p. 1058-1059). (For expansion see LaFond, 1951.)

13. 10^5 $\delta_{s,p}$ as obtained from Tables IVa and IVb of *The oceans* (appendix, p. 1056-1057). (For expansion see LaFond, 1951.)

14. 10^3 δ as obtained by applying pressure corrections in columns 12 and 13 to base values of $10^5 \triangle_{s,t}$ given in column 11.

15. Means of 10^5 between successive depths as obtained from column 14.

16. Geopotential anomaly between successive isobaric surfaces expressed in dynamic meters. These values are the product of means of 10^5 (column 15) and corresponding depth increments obtained from successive depth differences in column 5.

17. Cumulative anomalies of dynamic depth (dynamic meters) of the corresponding isobaric surfaces (column 5) summed by adding successive values in column 16. The depth of any isobaric level in dynamic meters can be obtained by adding the anomaly (column 17) to the corresponding values for standard isobaric reference levels given in *The oceans*, Table II, appendix, p. 1054.

Note: For bibliographical references to the subject matter contained in this fascicule *see* 2.3.5 References, at end of Fascicule 7.

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